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TITLE: HIGH-EFFICIENCY FREE-ELECTRON LASER RESULTS

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HIGH-EFFICIENCY FREE-ELECTRON LASER RESULTS

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ABSTRACT

Results obtained with a tapered-wiggler free-electron laser show deceleration of electrons by as much as 7%, and extraction of more than 3% of the total electron-beam energy as laser energy.

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Theoretical predictions have indicated that by properly varying (tapering) the period and strength of the wiggler field in a free-electron laser, the energy extracted from the electron beam as laser radiation can be increased from a few tenths of one per cent to several percent or more (1). According to these predictions, at sufficiently high incident laser power (of the order of a gigawatt) some of the electrons become trapped in stable-phase regions ("buckets") of the ponderomotive potential created by the incident laser and wiggler fields. Since the "buckets" can be decelerated by properly tapering the wiggler field, the trapped electrons can be decelerated as well to extract of the order of 10% of their energy as laser radiation. The untrapped electrons remain near their original energy and contribute little to the radiation field.

To test this theory, an experiment has been carried out with a 20-MeV electron beam, as shown in Fig. 1. The electron beam had an average current of about 250 mA, an energy spread of 0.5%, an emittance of 0.5 π mm-mrad, and a pulse length of 5 ns. The CO_2 laser had a peak power of 1 GW, operating on a single longitudinal and transverse mode, with a pulse length variable from 1 to 10 ns. The wiggler was 1 m long and used $SmCo_5$ permanent magnets to create a 0.3-T field with a period tapered from 2.7 cm at the entrance to 2.4 cm at the exit. Under design operating conditions, about half of the

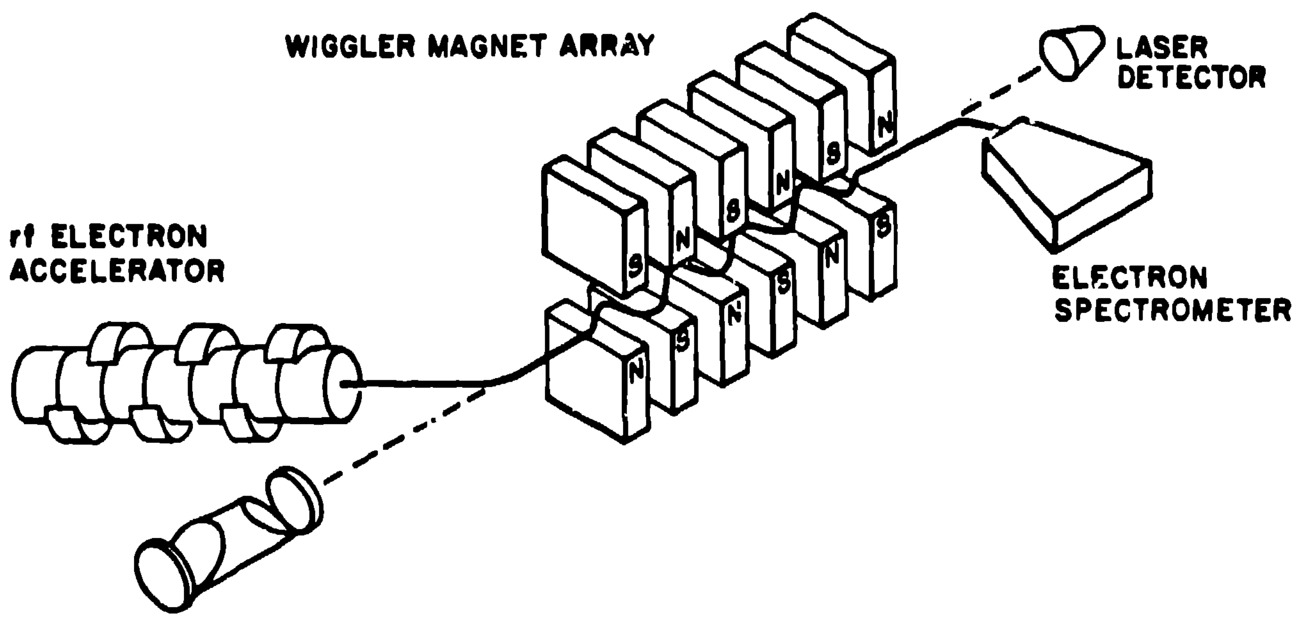

Fig. 1. Schematic diagram of the Los Alamos free-electron laser experiment (AP-1-VG-8148B-1).

electrons are predicted to become trapped in the "ponderomotive potential" and be decelerated about 7% (2). The average deceleration under these conditions is predicted to be more than 3%. As shown in Fig. 1, the experimental diagnostics included an electron spectrometer to measure the energy spectrum of the electrons leaving the wiggler and an optical detector to measure the amplification of the CO_2 laser beam (3). Only the results of the electron spectrometer are discussed here.

A typical electron spectrum is shown in Fig. 2. The spectrum displays the double-peaked electron-energy distribution function predicted by theory. The high-energy peak near the original energy contains those electrons not trapped in the ponderomotive potential, while the low-energy peak contains those electrons trapped in the ponderomotive potential and decelerated with the taper in the wiggler period. For the conditions of this measurement, the trapped electrons represented about 60% of the total and were decelerated about 6.5%. The total extraction (corresponding to the average deceleration of the electrons) was about 3.5% of the initial electron energy. This is about an order of magnitude larger than has been obtained in experiments using uniform (untapered) wigglers.

As shown in Fig. 3, the average energy extracted from the electron beam depended on the initial energy of the electrons. Maximum extraction occurred when the electrons entered at the resonant energy, corresponding to the velocity of the potential energy wells at the wiggler entrance. In fact, by injecting the electrons at too low an energy, they could be accelerated instead of decelerated, corresponding to laser absorption instead of gain.

Figure (4) shows the saturation behavior of the amplifier as the input laser power was increased. Since the slope of a line connecting the origin

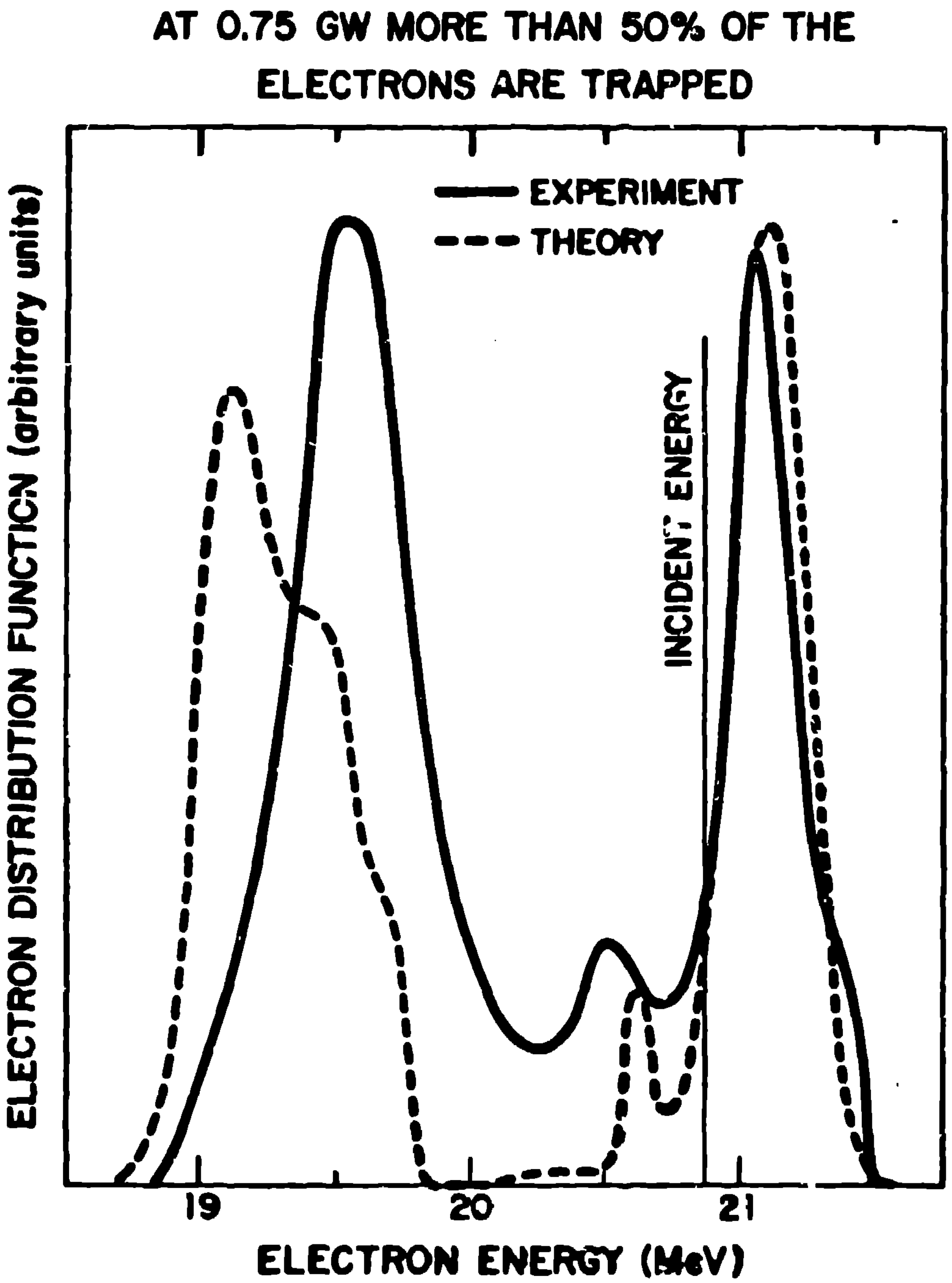

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Fig. 2. Electron distribution function at an input optical power of 0.75 GW (AP-1-VG-9231).

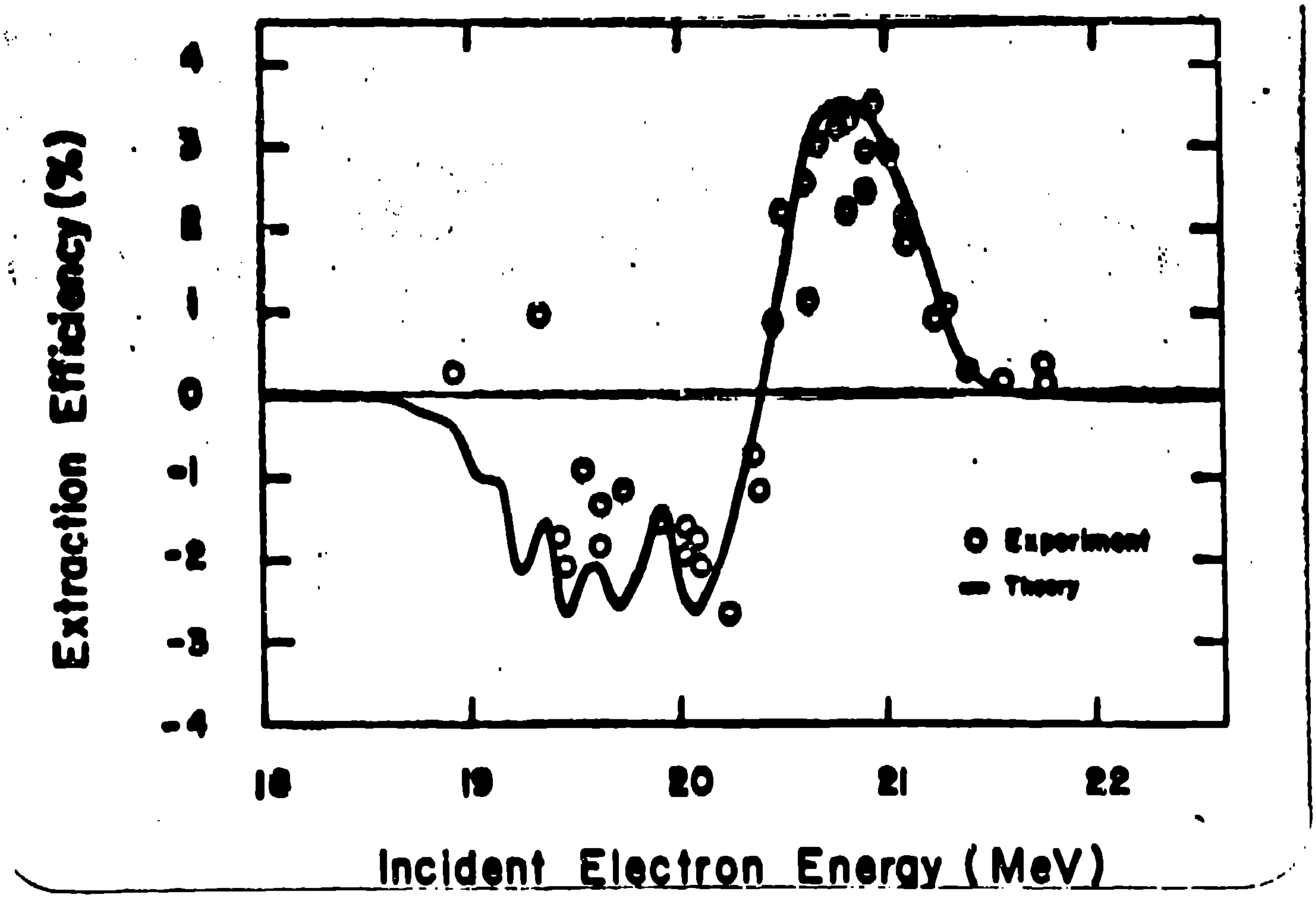

Fig. 3. Average energy extraction at an input optical power of 0.75 GW (AP-1-VG-9548).

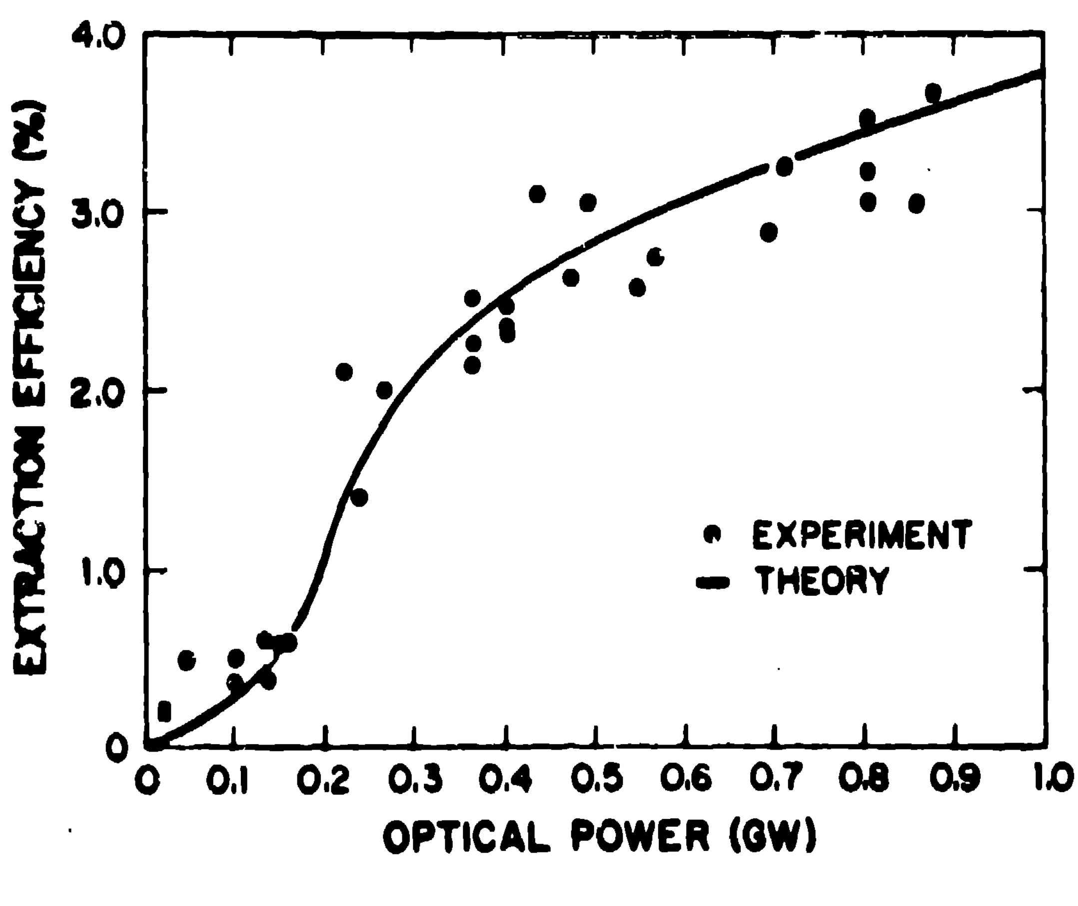

Fig. 4. Saturation of the free-electron-laser amplifier at an incident electron-beam energy of 20.9 MeV (AP-1-VG-9226).

with a given data point is proportional to the amplifier gain, it is clear that the small signal gain (below about 0.2 GW) was smaller than the saturated gain (from about 0.2 to 1.0 GW). This is in good agreement with theoretical predictions. The inflection point near 0.2 GW is due to the threshold (around 0.1 GW) for the formation of stable-phase regions ("buckets").

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